Collaborative Proposal to Extend ONR YIP research with BRC Efforts

Brian Powell, Ph.D.
University of Hawaii
1000 Pope Rd., MSB
Honolulu, HI 96822

phone: (808) 956-6724   fax: (808) 956-9225   email:powellb@hawaii.edu

LONG-TERM GOALS

The long-term scientific goals of this research project are:

1. To develop an understanding of how some sources of error affect ocean predictability.

2. To gain experience and develop ideas for the limitations to the predictability of oceanic processes.

OBJECTIVES

The primary objectives of this project are: (i) to undertand the importance of model uncertainty; (ii) to assess the influence of uncertainty on predictability; and (iii) to collaborate and learn from fellow BRC projects.

APPROACH

To improve forecasts of the ocean circulation, we must deal with many scales of physical processes and how they are represented within numerical models. The ocean contains energy at many scales from planetary (megameters) down to small turbulent mixing (centimeters). The dominant range of energy exists in the mesoscale. Most of the efforts on assimilation and predictability are concerned with the mesoscale and even submesoscale. There are some regional seas where energy at other scales are of similar strength. Regions such as Hawaii, South China Sea, Philippine Sea, and others contain significant baroclinic internal wave energy generated by the conversion of the barotropic tides. The energy of these internal tides interacts with the mesoscale with higher energy modes dissipating quickly into the background flow leaving low mode baroclinic waves. The interaction between the mesoscale and internal waves is an active area of research in the ocean, and is not well understand how energies cascade between the two scales.

We continue to be the forefront of working to both represent and assimilate data in regions where baroclinic tidal flows are as great as the mesoscale, primarily Hawaii and the Philippine Sea, both of which are important strategic regions for the Navy. Around Hawaii, internal tides heave the thermocline over 100m as they propagate and greatly affecting *in situ* observations from platforms such as gliders, acoustic tomography, moorings, etc. For fixed observations with frequent

1. REPORT DATE **30 SEP 2012**	2. REPORT TYPE	3. DATES COVERED **00-00-2012 to 00-00-2012**
4. TITLE AND SUBTITLE **Collaborative Proposal to Extend ONR YIP research with BRC Efforts**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Hawaii,1000 Pope Rd., MSB,Honolulu,HI,96822**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

enough observations, these signals are easily identified; however, in non-traditional observations, the internal wave signals typically cannot be extracted. For instance, as gliders pass through time and space, there is a smearing of the internal wave energy. Likewise, heaving of the density surfaces by internal waves changes the propagation of sound impacting tomographic measurements. The surface bounce of internal waves has a random phase due to density variations in the background stratification, which impacts high-frequency radar measurements adding significant uncertainty in the estimate of the surface flow.

In addition to the internal waves, accurate representation of the surface layer between the ocean and atmosphere has been found to be a significant issue for our studies due to strong diurnal variability in sea surface temperature, and rapid forcing by wind shifts in the upper waters that are captured by the HF radar. Because both of these datasets are assimilated in near real-time by our system, the model must represent the processes as well as possible, which requires a better surface layer representation.

The ocean model used in this research is the ONR-funded Regional Ocean Modeling System (ROMS): a free-surface, hydrostatic, primitive equation ocean model discretized with a terrain following vertical coordinate system. The model has multiple sub-gridscale parameterizations of vertical mixing along with many options for open boundary conditions. Time-splitting of barotropic and baroclinic motions enables efficient time integration. ROMS has been successfully used to model many regions of the world ocean (see `http://www.myroms.org/papers`) and is a widely used community resource.

WORK COMPLETED

During the current reporting period, with a new postdoctoral scientist, we have worked to re-formulate the representation of the surface layer of the ROMS model to improve the vertical discretization used in regions with sharp bathymetric changes. This new formulation allows for better representation of sea surface temperatures (as compared to observations) and variability in diurnal cycles of heating and cooling. This work is currently being prepared for submission.

Since the previous report, we have completed the work to understand the impact of internal waves on predictability of regional oceans of Hawaii and the North Philippine sea. Along with a graduate student, Colette Kerry, who is supported under ONR #N00014-09-1-0939, we have published two studies on the effects of remote internal wave generation on location tidal conversion. The first was for the Hawaiian region that showed local conversion is as sensitive to remote effects as it is to local stratification changes due to advection Powell et al. (2012). In a second paper covering the Philippine Sea, we found that two generation sites (the Luzon Strait and Mariana Island Arc) are coupled: the internal tides generated at one affect the generation of internal tides at the other. This feedback can create considerable variability in the baroclinic energy fluxes from each site (Kerry et al., 2012).

In the year one report, we noted the work to understand the length scales of variability in collaboration with another BRC member, Ralph Milliff. This paper (Matthews et al., 2011) was published in 2011.

RESULTS

As part of the ongoing efforts of my Young Investigator Program award (ONR #N00014-09-1-0939) as well as the operational NOAA Integrated Ocean Observing System, we have built an

operational, real-time assimilation and prediction system for the main Hawaiian islands. This system provides a foundation laboratory for research into state estimation and predictability. In support of these efforts, we have worked to better represent the highly variable representation of the interface between the ocean and atmosphere to improve our predictions and assimilation of sea surface temperature and HF radar data.

Using the Hawaii model, we have developed a new stretching function for ROMS that imposes a tight grouping of 2-3 layers in the very near surface. This allows us to slightly increase the number of layers in the model, which does not contribute significantly to the numerical cost, and to insure that we maintain the same distribution of layering as our prior model with increased density in the surface. As shown in Figure 1, the current ROMS stretching function is linear; however, the new function is quadratic, which imposes a tighter spacing in the near surface. This results in a significant decrease in the thickness of the surface layer, from an average of 8 m thick around Hawaii to under 2 m thick (see Figure 2).

In the lee of the islands, the diurnal cycle in sea surface temperature may vary as much as $1°C$, and in the previous formulation, it required a great deal of heat loss/gain to cool/warm the upper 8 m of water. This created issues in the assimilation (Matthews et al., 2012) with artificial upwelling needed to cool the water for night-time SST measurements. We are conducting new experiments with a 2 year assimilation reanalysis to compare the new stretching function.

Around Hawaii, nearly 3GW of energy is converted by the M_2 tide at Kaena Ridge between Oahu and Kauai. Focussing upon this ridge, but considering the significant semidiurnal tides (M_2, S_2, N_2), we determined the contribution of the oceanic flow to the conversion. As shown in Figure 3, the sensitivity of baroclinic conversion across Kaena ridge to temperature varies throughout the year, but is nearly equal between the downward phase (remotely propagating waves) and the upward phase (local stratification) propagation regions.

This has important impacts for our predictability because it shows that not only do we need to get the local conversion correct to match the observations that capture the baroclinic energy, but we must also get conversion of other areas correct due to the impact that they have on local conversion. This problem will grow as more regional applications begin to consider tides.

IMPACT/APPLICATIONS

Many groups are assimilating SST, and those that wish to use time-sensitive swath data may find it far more useful to utilize the new stretching function being developed because it allows for diurnal variability and momentum flux.

Internal tides have become an important factor in the predictability of the ocean. In deeper oceans, the non-hydrostatic component of internal waves is negligible, which means that internal waves are present and crucial to the state estimation in existing models. As models move into very shallow waters, only non-hydrostatic models would be capable of resolving internal waves; however, in the present, it is important to reduce the uncertainty from tidally induced internal waves before stepping down in scale.

TRANSITIONS

We have published four papers with partial support from this project (with the remaining support from #N00014-09-1-0939). Another paper is in preparation detailing the new stretching function.

This project also helps to train future scientists in predictability as it allows me to support them on the other grant.

RELATED PROJECTS

This project is collaborating with the following ONR supported projects:

- "A community Terrain-Following Ocean Model (ROMS)", PI Hernan Arango, grant number N00014-08-1-0542.

REFERENCES/PUBLICATIONS

C. G. Kerry, B. S. Powell, and G. S. Carter. Effects of remote generation sites on model estimates of M_2 internal tides in the Philippine Sea. *J. Phys. Oceanogr.*, in press, 2012.

D. Matthews, B. S. Powell, and I. Janeković. Analysis of Four-dimensional Variational State Estimation of the Hawaiian Waters. *J. Geophys. Res.*, 117(C03013), 2012. doi: 10.1029/2011JC007575.

D. Matthews, B. S. Powell, and R. F. Milliff. Dominant Spatial Variability Scales from Observations around the Hawaiian Islands. *Deep-Sea Res., Part I*, 58:979–987, 2011.

B. S. Powell, I. Janeković, G. S. Carter, and M. A. Merrifield. Sensitivity of Internal Tide Generation in Hawaii. *Geophys. Res. Let.*, 39(L10606):1–6, 2012. doi: 10.1029/2012GL051724.
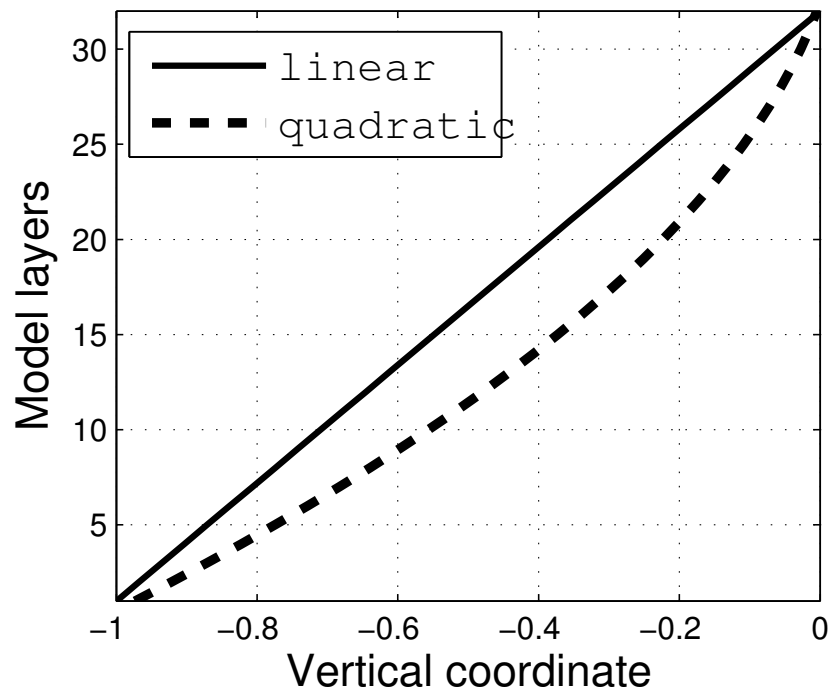
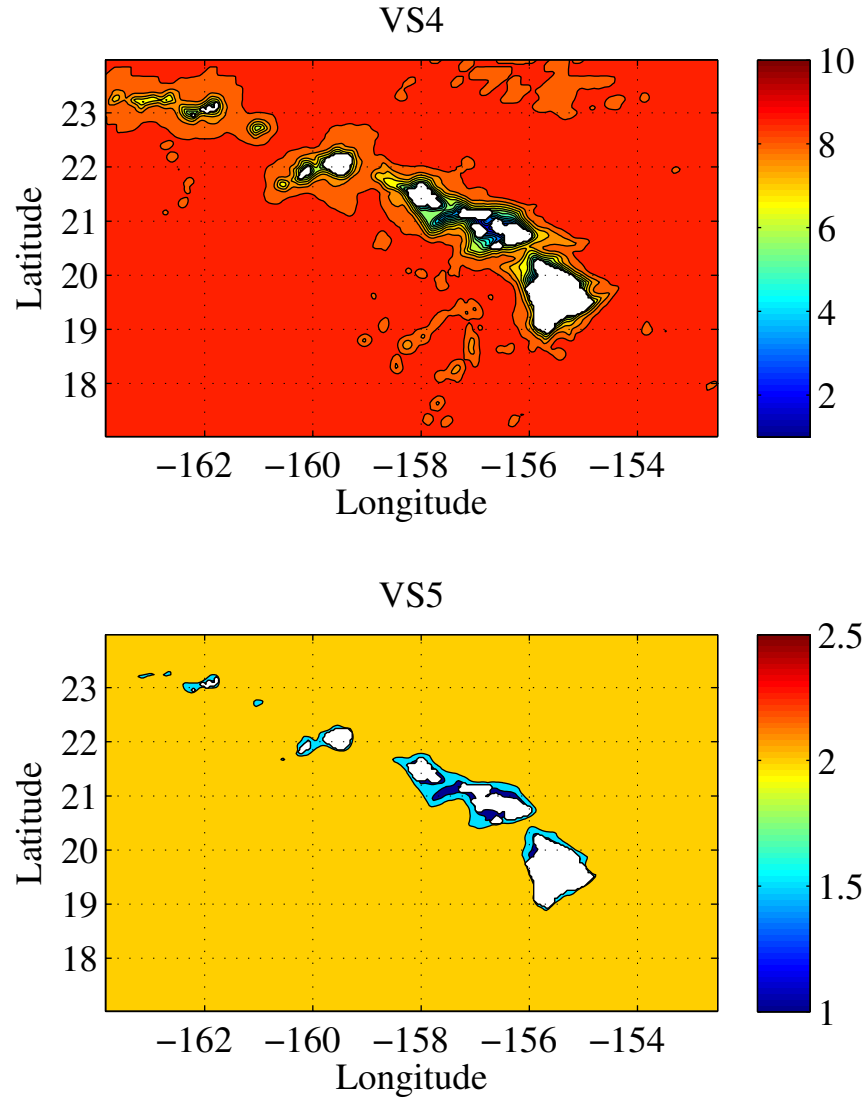Figure 1: Comparison of current ROMS stretching and the new quadratic as a function of sigma.

Figure 2: The depth of the surface layer in the model for the Hawaiian region. The current ROMS function generates a surface layer of 8m thickness versus the new formulation that is less than 2m.
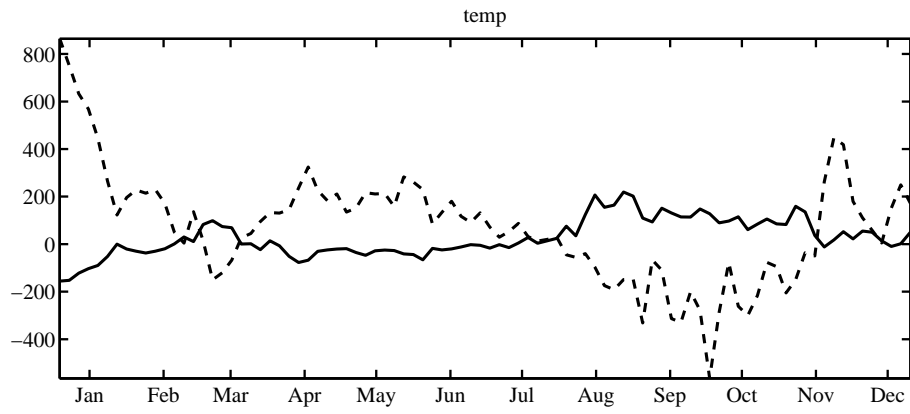
Figure 3: The sensitivity of the tidal conversion at Kaena ridge to temperature changes in the upper 700 m (solid line) and deeper than 800 m (dashed line) over a full year.